



Roman lead ingots from Macedonia—the Augustan shipwreck of Comacchio (prov. Ferrara, Italy) and the reinterpretation of its lead ingots' provenance deduced from lead isotope analysis

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Abstract

A shipwreck of the 3rd/2nd decade BC found near Comacchio (prov. Ferrara, Italy) in 1980 contained not only well-preserved technical equipment and commercial goods but also 102 Roman lead ingots. Since then, the origin of the ingots has been intensively discussed. Domergue et al. (2012) connected the epigraphic elements with lead isotope analyses and favored the southeastern Spanish lead ore mines being the source of the lead metal. An origin from the Balkan region (Illyricum) was favored by Dušanić (2008). Due to our investigations, both assumptions cannot be maintained. We present a new interpretation of the lead's isotope signature which best match data of ore deposits from Chalkidiki, Thasos island, and Pangaion mountains in the northern Aegean region.

Keywords Comacchio shipwreck · Roman lead ingots · Lead isotope analysis · Provenance study · Reinterpretation · Chalkidiki · Thasos · Pangaion

Introduction

In autumn 1980, the remains of a Roman cargo ship of the 3rd/2nd decade BC came to light in the Valle Ponti lagoon northwest of Comacchio (pr. Ferrara, Italy) and about 20 km southwest of today's Po estuary (N 44.706, E 12.164) (Fig. 1). The ancient wreck was excavated by the Soprintendenza Archeologica dell'Emilia-Romagna between 1986 and 1989 (Berti 1990). In addition to the excellent preservation of the wreck with the ship's technical equipment and personal items of the crew or fellow travelers, the ship protrudes through a load of 102 lead ingots with a total weight of 3.1 tons and 28 trunks of boxwood. Other finds

like amphorae cannot be clearly identified as cargo or on-board equipment (Parker 1992). Since the discovery of the Comacchio shipwreck, the ingots in particular have drawn interest. A controversial debate developed regarding their provenance (Illyricum or Hispania) and economic significance (Domergue 1987; Berti 1990; García-Bellido 1998a, b; Dušanić 2008; Domergue et al. 2012).

According to the more scientifically oriented readership of this journal, we decided to focus on the lead isotope investigation and interpretation but will also provide key information from epigraphy and archeology to support the analytical data-based conclusion. Full description of the ingots of Comacchio will be soon accessible in our monograph 'Corpus of Roman Lead Ingots' (hereinafter: CRLI) (see bibliography: Rothenhöfer et al. [forthcoming]).

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Roman lead ingots and their archeological value

Why are Roman lead ingots so enlightening for the reconstruction of mining in Roman time? Antique texts give important, but often quite limited information. Archaeological traces of mining also rarely allow a deeper insight into the size, duration, and intensity of exploitation, especially since ancient mining places were often completely



Fig. 1 Map showing the Italian mainland in the center with the find location of the Comacchio shipwreck (M. Bode)

destroyed by younger economic activities. On the other hand, mining products like lead ingots can contribute to a significant gain in knowledge as they often bear inscriptions, trademarks, and stamps referring to persons involved in mining and trade. In some cases, they even contain information about the origin of the metal (e.g., *BRIT(annicum)*, *GERMANICVM plumbum* = *British or German lead*) (see, e.g., Hanel and Rothenhöfer 2013). This information can be combined with archaeometallurgical data.

Previous studies on the Comacchio ingots

Domergue (1987) presented 99 of the 102 ingots. With the presentation of the types of ingots and epigraphic elements, he had already turned to questions about the historical and the economic significance of this shipload. With regard to the origin of the lead ingots, at that time C. Domergue ruled out a provenance from the Iberian Peninsula and rather considered a production within the Balkans. This first interpretation was carried out without the use of scientific analyses. In contrast to this, analytical investigations (mass spectrometric and neutron activation analyses), mentioned in a note in Berti (1990), led to the consideration of an origin from Spain.

In the 1990s, M.-P. García-Bellido proposed a military reading of several of the stamps which can be found on the ingots and connected them with production centers in the southwestern Extremadura of Spain (Baeturia: Azuaga and La Serena, prov. Badajoz) (García-Bellido 1995, 1998a, b, 2000). Both her interpretation of the stamps and the alleged provenance are untenable. For example, she connected the stamp MAC with the *legio IV Macedonica* (13 stamps on 12 ingots of type B5 and C3; see Figs. 2 and 3). That would be unique—at least on lead ingots. Much more plausible is the reading of MAC as a cognomen like Macer, Macedo, or Macrinus. As such it can be connected to the C. MATI-stamp (7 stamps on 4 ingots of type B5), both giving us the name of an entrepreneur, Gaius Mati(us?) Mac(er?). The use of two stamps to indicate the full name of an entrepreneur can also be observed on other lead ingots. As in the example of the abbreviation MAC, she also interprets the stamp GEME(...) (24 stamps on 18 ingots of type B5 and C3; see Figs. 2 and 4) as military. She refers here to the *legio X gemina* or *gemella*. The reading of the ingot stamps presented by García-Bellido was already rejected by Domergue et al. (2012).



Fig. 2 Pictures of a caduceus symbol (center) as well as four different stamps, mentioned in the text: GEME(...) (top left), L(ucii) CAE(...) BAT(...) (bottom left), AGRIP (top right), MAC (bottom right) (N. Hanel)

In 2008 S. Dušanić published new ideas about the origin of the lead cargo (Dušanić 2008). After a detailed analysis of the epigraphic elements, he advocated a provenance from Illyricum, even considering a production outside the borders of the empire by Illyrians in the Barbaricum. But the uniformity of the ingots and the use of cartouches with a caduceus motif, which is hardly to be expected in this way in the Barbaricum, in our view speak against this assumption. At the latest, the use of stamp inscriptions, which are predominantly to be interpreted as Latin name elements, must have taken place on Roman-controlled territory. As a suggestion for the origin of the ingots, he linked the Agrippa stamps with the rich silver-lead mountain areas in the vicinity of the Celtic (later Roman) city Sirmium (Sremska Mitrovica) in northwestern modern Serbia and constructed a connection to the (*metalla* or *argentariae*) *Agrippi(a)na* which Augustus in late 13 or 12 BC should have bequeathed to Agrippa. Not only were these mines first mentioned much later at the end of the 3rd century AD (Codex Iustinianus 5.12.21), but also amongst other things the name of the locality Agrippina is less likely derived from Agrippa, but from Agrippina.

Conclusions based on the epigraphical elements on the Comacchio ingots

Generally, compared to other contemporary lead ingots, the cartouches and inscriptions on the lead load from Comacchio show striking differences. Noteworthy is the lack of molded inscriptions in cartouches on the top of the ingots (47 ingots of type A2 and B4 with molded inscriptions); almost all ingots from the mining areas around Carthago Nova were provided with this significant epigraphic element providing the names of the entrepreneurs. Instead of personal names, the caduceus—a widespread symbol of trade in Roman times—dominates in almost half of the lead ingots from Comacchio. The caduceus motif is already known on lead ingots from the 1st third of the 1st century BC from the mining area around Carthago Nova. However, the caduceus never appears alone on Hispanic lead ingots, but always in combination with the name of an entrepreneur. Regarding the Comacchio ingots, it can be noted that the caduceus motif is found in cartouches of ingots from different mining regions (compare Table 3).

The ingots also stand out due to their numerous stamps; 12 ingots are marked with 6 different stamp types. About two-thirds of the lead bears impressions of three to five different stamps. A clear sequence of the various stamps cannot be made out with certainty. Rather, they give the impression that they were stamped into the ingots more or less within a very short time and possibly even at the same place.

By far the most important epigraphic element is the AGRIP-stamp (Fig. 2), referring without doubt to Marcus Vipsanius Agrippa, the famous general, confidante, and son-in-law of Augustus and statesman (64/63–12 BC). The stamp AGRIP appears 189 times on 96 Comacchio ingots of all types. It can be ruled out that the AGRIP stamp is a control mark. In that case, Agrippa should have been involved in supervising the production of the Macedonian *metalla* and in controlling the distribution of the lead metal. So far there are no indications for this. If this were to be assumed, however, the L. CAE BAT stamp (Fig. 2), which can be found comparably frequently (120 times on 97 ingots) and is considered to name either a freedman or the son of a freedman of Caecilia Attica, the first wife of M. Agrippa or of his father-in-law Q. Caecilius Q. f. Pomponianus Atticus (Domergue 1987), would have to be interpreted in a similar way. But such a double control would be extremely unusual.

An interpretation as an owner's mark is much more convenient, also under the impression of a possible connection of L. Cae (...) Bat (...) to the *familia* of Caecilia Attica and thus to Agrippa. In this case, Agrippa and his wife would have bought lead (presumably via a freedman) from various mines in Macedonia and had it transported to northern Italy.

Data collection for the provenance study

In 2012, Domergue et al. published a detailed counter position to the previous formulated interpretations of the lead cargo of the Comacchio ship (see above). For this purpose, 20 of the 102 lead ingots were examined via lead isotope compositions. The authors distinguished two groups, the largest of which was assigned to the Cartagena-Mazarrón mining area or the Sierra Almagrera (pr. Almería) and the small group with three ingots directly connected to the Cartagena-Mazarrón area (pr. Murcia).

In the following chapter, “The origin of the lead I (lead isotope analysis),” on the basis of these published and own lead isotope analyses (Table 3, Figs. 5 and 6), we will exclude the Spanish lead ores as a source of the Comacchio ingots and will favor instead the northern Aegean lead ore districts of the Chalkidiki, the island of Thasos, and the Pangaion mountains in Roman Macedonia (see map in Fig. 3).

Ingot types and sampling strategy

Four different types of ingots can be basically identified in the shipwreck (see Fig. 4 and Table 1). In the course of our workings on the CRLI monograph, we established a classification of ingots, to which we refer here. Type A2 has a rounded top which is somewhat flattened. The two narrow sides of the ingots are vertical or only slightly slanted. Type

Fig. 3 The Serbo-Macedonian massif and Vardar Zone on the Chalkidiki peninsula, the Pangaion, and Lekanis mountains as part of the Greek Rhodopes as well as the island of Thasos (M. Bode)



Fig. 4 Pictures of the ingot-types A2, B4, B5, and C3 from the shipwreck of Comacchio (N. Hanel)

B4 has a truncated and elongated pyramidal shape and strikingly flat-angled narrow sides. Type B5 resembles a loaf of bread, i.e., the top and the two narrow sides are more or less rounded. The shape of the ingots of type C3 is almost cuboidal or long rectangular with trapezoidal cross section, i.e., the top always has slightly shorter dimensions than the bottom of the ingot. During our investigation, almost exactly those ingots (5 of ingot-type A2, 3 of B4, 10 of B5, together 18 samples) were sampled in the same drill hole for a chemical analysis from which material had already been taken by the team around C. Domergue for lead isotope measurements.

Table 1 Type-classifications of the ingots of Comacchio according to their shapes

Publication	Ingot type	Ingot type	Ingot type	Ingot type
this study	A2 ($n=42$)	B4 ($n=5$)	B5 ($n=47$)	C3 ($n=8$)
Domergue et al. (2012)	Ser. IV	Ser. V	Ser. I–III	
Domergue (1987)	Type IIIa	Type IIIb	Type I	Type II
Berti (1990)	Grupo 4	Grupo 5	Grupo 1	Grupo 3

Regrettably, we did not drill the ingots of type C3 for a laboratory test at that time. We conducted trace element analysis on all 18 samples, as well as lead isotope analysis on 12 of those samples (see Tables 2 and 3).

Methodology

The trace element analyses were carried out in the HfMA (House for Material and Analytics) of the Deutsches Bergbau-Museum Bochum with a HR-ICP-MS (high-resolution-inductively coupled plasma-mass spectrometer) (Element XR, Thermo Fisher Scientific). Before this for each sample, ca. 100 mg of cleaned lead metal was dissolved in 5 ml of concentrated HNO_3 and 3 ml $\text{H}_2\text{O}_{\text{dest.}}$ and a 1000 mg/l stock solution prepared. They were diluted 1:10 for the trace element analysis with 5% HNO_3 . The individual trace elements were quantified using an external calibration. The results were checked with lead standards PG 3 to 5 (Brammer Standard Company, Inc., Houston, USA) (results in Table 2).

The lead isotope analyses were performed in the Frankfurt Isotope and Element Research Center (FIERCE). For lead isotope determination with a MC-ICP-MS (multi collector-inductively coupled plasma-mass spectrometer) (Neptune Plus, Thermo Fisher Scientific), around 40 samples are usually measured automatically in a series. For this purpose, the dried-up lead eluate of each metal sample is diluted to about 125-ppb Pb with 2% HNO_3 . A 10ppb concentrated Tl standard solution (NIST SRM-997) is then added for internal fractionation correction. The lead standard NIST SRM-981 is used as unknown sample to check the accuracy of the analysis results and the stability of laboratory and

instrument conditions (mass drift) after every 5 samples (results in Table 3).

The origin of lead I (lead isotope analysis)

As mentioned before, according to the lead isotope comparison—in combination with epigraphic and historical considerations—Domergue et al. (2012) concluded that the lead ingot load should have been exported from southeastern Spain (Cartagena-Mazarrón, Sierra de Almagrera). This mineral-rich area, which was already exploited for lead in pre-Roman times and even more so also under Agrippa in the Roman period, is certainly a potential candidate like mining archaeology as well as several provenance studies on lead ingot complexes prove (compare, e.g., Ramallo Asensio 1985; Trinchieri et al. 2009; Domergue et al. 2016; Baron et al. 2017; Bode et al. 2017; Rothenhöfer and Bode, 2018). But the lead isotope diagrams in Fig. 5 clearly show that the Miocene lead ores from Murcia (Sierra de Cartagena, Sierra de Mazarrón) (black squares) and also from the neighboring province of Almería (Sierra de Almagrera, Sierra de Gador, Sierra de Alhamilla, Cabo de Gata) (white squares) do not come into question as they do not even overlap the ingot data clouds (black crosses) (ore geology and geologic-tectonical map of the Betic Cordillera; see Arribas and Tosdal 1994, Fig. 2, with listed locations). The same result could be obtained from a comparison with lead ore data from the old mines of the Balearic Islands or Catalonia, where no large-scale lead production in Roman times is evident (not shown) (compare data, e.g., from Canals and Cardellach

Table 2 Results of the trace element measurements for 18 lead ingots from Comacchio in wt.%. Other elements such as Ni, Co, Te, or Se occur in insignificant amounts or were below the limit of quantification

Arch. inv. no	CRLI no	Ingot type	Ag	As	Bi	Cu	Fe	Sb
54,847	50	A2	0.016	0.080	0.006	0.09	0.001	0.10
57,086	82	B4	0.020	0.042	0.007	0.10	0.001	0.23
57,106	83	B4	0.017	0.038	0.081	0.11	0.049	0.18
54,835	85	B4	0.007	0.110	0.075	0.39	0.001	0.26
57,090	58	A2	0.017	0.003	0.006	0.56	<0.001	0.02
54,840	70	A2	0.015	0.770	0.007	1.20	0.003	0.14
57,088	71	A2	0.015	0.270	0.009	0.18	0.001	0.13
54,839	75	A2	0.009	0.011	0.006	0.09	0.007	0.09
54,859	88	B5	0.002	0.006	0.003	0.47	0.001	0.06
54,851	97	B5	0.009	0.410	0.003	1.31	0.010	0.17
54,854	98	B5	0.005	0.490	0.002	0.94	0.002	0.14
54,864	101	B5	0.009	0.400	0.005	0.94	0.021	0.31
54,869	112	B5	0.013	0.004	0.006	0.12	0.005	0.02
57,065	117	B5	0.005	0.330	0.006	0.55	0.007	0.20
57,126	123	B5	0.002	0.730	0.003	1.37	0.004	0.24
57,097	124	B5	0.009	0.130	0.007	0.50	0.026	0.28
57,093	128	B5	0.015	0.170	0.007	0.36	0.003	0.26
57,125	132	B5	0.008	0.400	0.003	1.33	0.028	0.17

Table 3 Lead isotope ratios of 20 lead ingots from Comacchio with suggested provenance. “Precision” of the published data in Domergue et al. (2012). Relative 2-sigma standard deviation of own values: $^{206}\text{Pb}/^{204}\text{Pb}=0.016$ to 0.11% , $^{207}\text{Pb}/^{204}\text{Pb}=0.019$ to 0.11% , $^{208}\text{Pb}/^{204}\text{Pb}=0.023$ to 0.11% , $^{208}\text{Pb}/^{206}\text{Pb}=0.010$ to 0.014% , $^{207}\text{Pb}/^{206}\text{Pb}=0.006$ to 0.014%

Arch. inv. no	CRLI no	Ingot type	$^{208}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$	Suggested provenance	Data source
57,097	124	B5	2.076	0.8381	18.692	15.665	38.802	Pangaion	Domergue et al. 2012
57,122	43	A2	2.074	0.8380	18.678	15.653	38.739	Pangaion	Domergue et al. 2012
54,847	50	A2	2.075	0.8385	18.700	15.679	38.805	Pangaion	CRLI
57,106	83	B4	2.068	0.8332	18.804	15.668	38.895	Chalkidiki/Thasos	CRLI
54,834	84	B4	2.066	0.8326	18.779	15.635	38.805	Chalkidiki/Thasos	Domergue et al. 2012
54,835	85	B4	2.066	0.8327	18.787	15.644	38.822	Chalkidiki/Thasos	Domergue et al. 2012
57,090	58	A2	2.073	0.8379	18.691	15.662	38.746	Pangaion	Domergue et al. 2012
57,132	63	A2	2.074	0.8380	18.683	15.657	38.742	Pangaion	Domergue et al. 2012
54,840	70	A2	2.075	0.8384	18.674	15.657	38.740	Pangaion	Domergue et al. 2012
57,088	71	A2	2.074	0.8382	18.675	15.653	38.730	Pangaion	CRLI
54,839	75	A2	2.075	0.8383	18.703	15.679	38.815	Pangaion	CRLI
54,859	88	B5	2.075	0.8386	18.697	15.680	38.804	Pangaion	CRLI
54,851	97	B5	2.076	0.8385	18.701	15.680	38.816	Pangaion	CRLI
54,854	98	B5	2.075	0.8386	18.697	15.679	38.803	Pangaion	CRLI
54,864	101	B5	2.076	0.8386	18.695	15.679	38.811	Pangaion	CRLI
54,869	112	B5	2.076	0.8382	18.705	15.679	38.829	Pangaion	Domergue et al. 2012
57,065	117	B5	2.076	0.8385	18.696	15.677	38.810	Pangaion	CRLI
57,126	123	B5	2.076	0.8385	18.699	15.679	38.812	Pangaion	CRLI
57,093	128	B5	2.076	0.8386	18.696	15.678	38.813	Pangaion	CRLI
57,125	132	B5	2.076	0.8384	18.699	15.679	38.812	Pangaion	CRLI

1997; Montero-Ruiz et al. 2009; Rafael et al. 2010; Hunt Ortiz et al. 2014).

And even without already isotopically excluding the ancient lead ore mines in the Betic Cordillera of Iberia, the find spot of the shipwreck on the west coast of the Adriatic Sea alone, away from the usual transport routes in the western Mediterranean region (e.g., Herschend 1995; Domergue et al. 2016), justify an equally critical lead isotope comparison with the ancient lead mines further to the East. Those deposits bear mineralization likewise geologically young and thus lead isotopically similar composed like those in the Andalusian fold mountains in the West of the Mediterranean (compare e.g. Arribas and Tosdal 1994, Fig. 1).

Lead ore deposits in the Aegean region (Greece, NW Turkey, Cyprus), which form together with other polymetallic ores the so-called Aegean field in a lead isotope diagram (compare Pernicka et al. 1984; Gale and Stos-Gale 1992), and the Roman lead ore deposits of the Danube region here certainly come into question. Although Roman mining,

or at least its extent, has not been proven for the ancient deposits of the North Aegean, especially the Greek ancient mines of Laurion (Megala Pefka, Plaka, Kamresa, etc.), the Chalkidiki peninsula (Mavres Petres, Madem Lakkos, Olympias etc.), the Pangaion mountains (Nikisiani), and the offshore island of Thasos (Vouves, Marlou, Koumaria, etc.) with their available data have been shortlisted for the provenance study, furthermore the relatively nearby Roman mining areas of Serbia and the Kosovo (Šumadija, Kopaonik district). Lead isotope data also brought the ancient lead ore deposit of Tirebolu in northeastern Turkey into focus (about the deposits and ancient mining activities, see e. g. Unger and Schütz 1980; Wagner et al. 1986; Pernicka 1987; Chalkias et al. 1988; Gialoglou et al. 1988; Hauptmann et al. 1988; Meier 1995; Sayre et al. 2001; Wagner et al. 2003; Westner 2017).

Figure 6, in which the published data of these old lead production areas were brought together, shows a clear connection of the Comacchio ingots (black crosses) to the

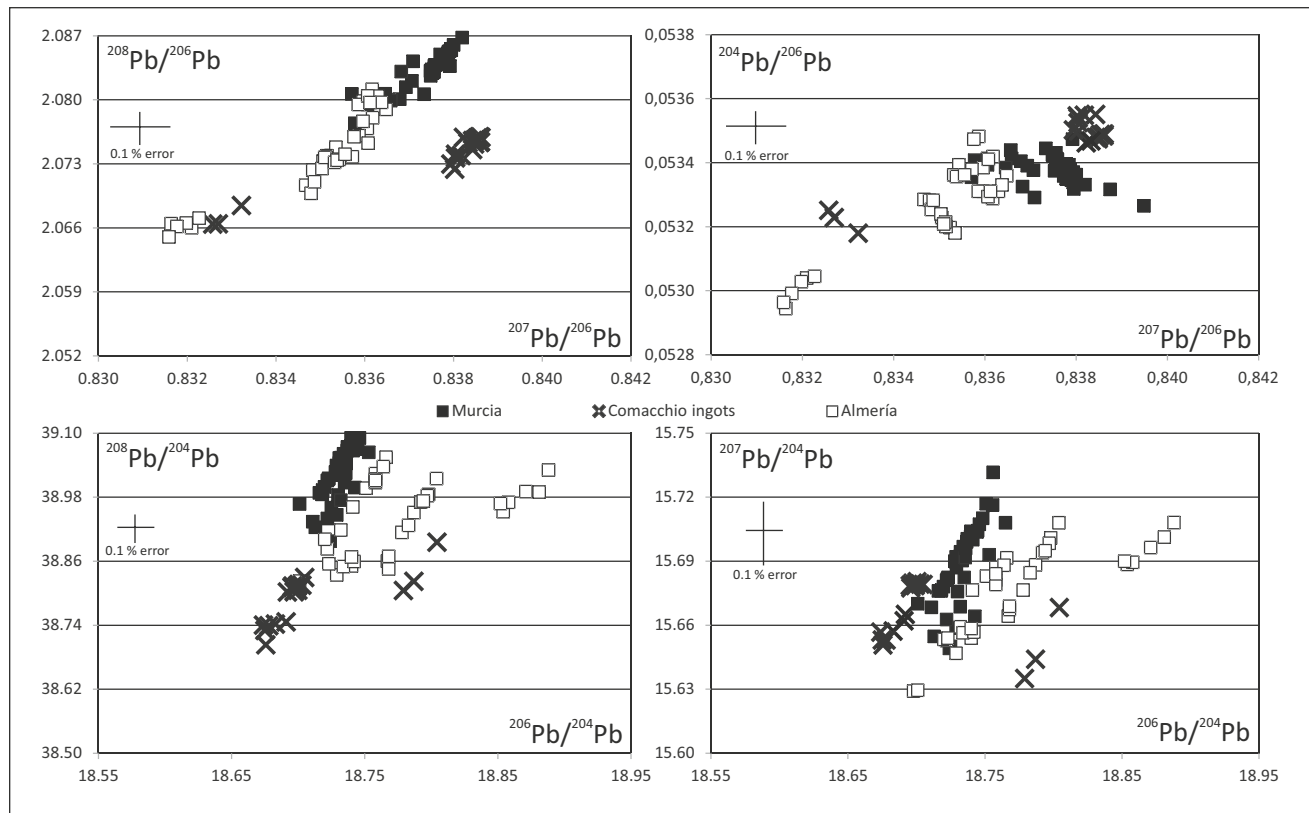


Fig. 5 Lead isotope ratio diagram-versions with data of lead mineralization from the provinces of Murcia (black boxes) and Almería (white boxes) in southeastern Spain as well as from 20 lead ingots from the Comacchio shipwreck (black crosses). According to the information provided by the ISOTRACE laboratory in Oxford, the error crosses (external reproducibility) refer to data generated with

a thermion mass spectrometer (TIMS) (all data without Müller et al. 2014; Baron et al. 2017; this study) (Dayton and Dayton 1986; Domergue et al. 2012; Arribas and Tosdal 1994; Stos-Gale et al. 1995; Trinchieri et al. 2001; Müller et al. 2014; Baron et al. 2017; this study) (M. Bode)

lead mineralizations of the Pangaion (grey circles) and the Chalkidiki ore deposits (grey diamonds), whereby in the latter case the ores of Thasos (white boxes) due to a few data outliers cannot be excluded. The Laurion (black squares) and the Serbo-Kosovar (white triangles) deposits are out of question. Interestingly, the ingot symbols form two narrow groups, the smaller one just made of B4 ingot types, coinciding with the data clusters of the Chalkidiki and partly of the island of Thasos, the bigger one with A2 and B5 types, falling into the Pangaion data field. A recent publication could also address fragments of a silver box from Mtskheta, Dedoplist Gora (Kareli district, Georgia) of the 1st century AD to the Pangaion ores (Parjanadze and Bode 2017). This is interesting, because the kingdom of Kartli was strongly politically influenced by Rome at that time.

Although further 1500 km distant from Comacchio than the island of Thasos or the Pangaion mountains, the ancient copper-lead mining area of Tirebolu-Esbiye, approx. 30 km east of Giresun on the Black Sea coast of northeastern Turkey, cannot be excluded clearly as a source for the ingots of type A2 and B5, which made up the largest part of the ingot

load. Not just its lead isotope signatures (white diamonds) (Sayre et al. 2001; Wagner et al. 2003), also mining archaeological information should not be passed over. At Tirebolu, ca. 50 pings evidently show ore exploitation in ancient times. And, in slag heaps, dated by ceramic finds from the Hellenistic-Roman period, remnants of litharge were found, testifying lead-silver extraction at that time (Seeliger et al. 1985). Nevertheless, at the current state of research, it seems rather less likely that lead was transported from outside of the Roman Empire on such a long waterway through the Black Sea and the Bosphorus.

To conclude, Fig. 6 allows the hypothesis that there are two relatively distinct lead mining centers in the Aegean producing metal at the same time, with the Pangaion ore deposits, according to the ratio of 89:5 for the different ingot type groups, apparently exporting in greater amounts.

The Pangaion is a relatively small mountain range running from southwest to northeast in northern Greece (Davies 1935/1979; Unger 1987; Meier 1995). The length is 25 km, its width 15 km. Exploitation of gold- and silver-bearing ores could be proven, whereby silver rather was a by-product of

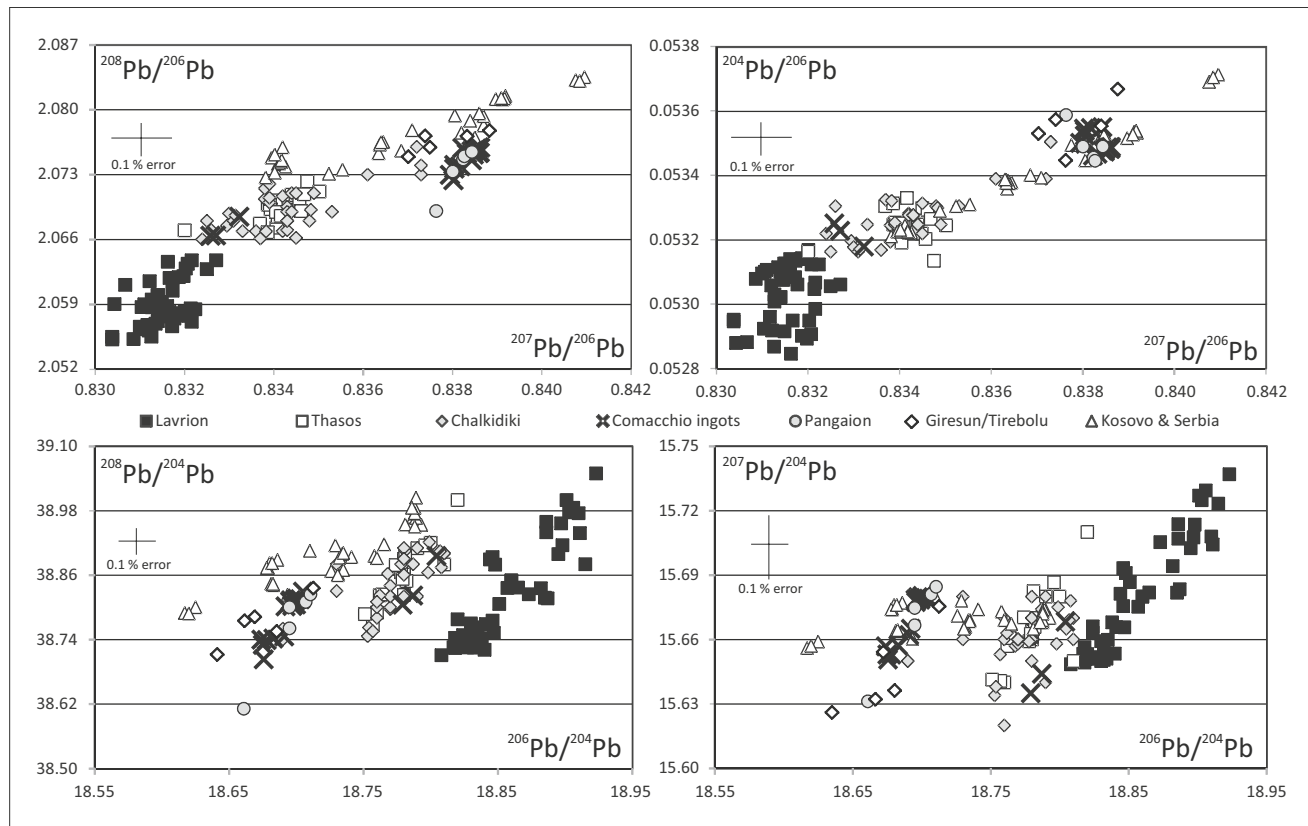


Fig. 6 Lead isotope ratio diagram—versions with data of lead mineralization from Laurion (black boxes), the Chalkidiki peninsula (grey diamonds), the island Thasos (white boxes), and the Pangaion mountains within modern Greece (grey circles) as well as from Serbia and Kosovo (white triangles), the ore deposits of Giresun/Tirebolu in modern Turkey (white diamonds), and from 20 lead ingots from the Comacchio shipwreck (black crosses). According to the information provided by the ISOTRACE laboratory in Oxford, the error

bars (external reproducibility) refer to data generated with a thermion mass spectrometer (TIMS) (all data without Westner 2017; this study) (Domergue et al. 2012; Gale 1980; Vavelidis et al. 1985; Wagner et al. 1986; Chalkias et al. 1988; Gale et al. 1988; Pernicka et al. 1993; Stos-Gale et al. 1996; Sayre et al. 2001; Wagner et al. 2003; Veselinović-Williams 2011; Westner 2017; OXALID (n.d.); this study) (M. Bode)

lead cupellation. The knowledge about the exploitation in antiquity is still fragmentary; previous investigations suggest overall mining activities from the end of the Neolithic to the Byzantine period (Unger and Schütz 1980, 1982; Unger 1981, 1987). The ancient mining area of the Chalkidiki is located in the northeast of the peninsula, with the most important lead-silver mines on the north and south flanks of the Stratonikon mountains. Galena shows relatively high Ag contents (0.21 wt.%). Ottoman and recent mining vastly destroyed the traces of antique activities; the roots of mining very likely go back to the Bronze Age (Davies 1935/1979; Wagner et al. 1986; Meier 1995). On Thasos the lead-silver mines are located on the western half of the island. The lead ores occur as galena and cerussite. The silver content is quite high in places (0.15 wt.%). There is evidence that mining lasted from the early Iron Age to the Byzantine era. Thasian coins minted with local silver are present until the first century BC. To our knowledge, no Roman lead ingot that could be assigned to the island of Thasos, the Pangaion, or the Chalkidiki have yet been identified.

Contrary to a very recent provenance study of Punic to Roman Republic silver coins treating lead isotope analyses and geological parameters statistically (Albarede et al. 2020), we present conventional 1:1 lead isotope data comparisons. Although the quality of TIMS-lead isotope data is not as good as MC-ICPMS lead isotope data, the combination of both data sets in this case study is sufficient to highlight the potential lead metal sources (Chalkidiki, Pangaion, Thasos) while safely excluding others in the region (e.g., Laurion, Serbia-Kosovo). It should also not be forgotten that Roman lead ingots are a very special group of objects which, in addition to their unmixed lead from a single source, can also hold other important information about their origin, especially through epigraphic elements. Nevertheless, one should generally not exclude neighboring deposits for which lead isotope investigations have not yet been carried out, but which were certainly known in ancient times for their metal richness—for example, those in the Lekanis mountains east of the Pangaion (see descriptions of the ore deposits in Vavelidis et al. 1996, 1997).

The origin of lead II (trace element comparison)

With regard to the lead's trace element pattern, concerning the B4 ingot group—even, (according to the relatively low Ag values) the lead might have been desilvered and the trace pattern noticeably changed (compare Pernicka and Bachmann 1983)—it seems reasonable to favor the Chalkidiki peninsula instead of the Thasos island as the more likely source of supply, since two samples (CRLI 83, 85) have significantly high Bi values like described by Wagner et al. (1986) for the lead mineralization there (Fig. 7) (it should be noted here that there is no lead isotope measurement for the ingot CRLI 82 with the low Bi values and its origin must remain open).

The presumed transport route

The route by which the lead ingots were transported from the deposits in Macedonia to the accident site of the ship cannot be determined with certainty. Because of the cheaper and faster sea transport compared to land transport, preference might have been given to shipping the lead ingots through the Aegean Sea (compare Drexhage et al. 2002).

In the case of the lead ingots coming from the Pangaion mountains, a relatively short land transport to a port can be assumed. The city of Amphipolis in the early principate would come into question; Amphipolis is now about 5 km from the sea coast at the Strymon River. Another way of shipping lead ingots from the Pangaion could have been to the east with the port of Neapolis (now Kavala). The linear distance from the mines in both cases is about 25 km. For the island of Thasos, the city of the same name had important seaports from where the lead cargo could have been shipped away (Marc 2019). Which port in the Chalkidiki was considered for the export of the lead ingots cannot be clarified at the moment.

The further route of the lead freight from Macedonia must remain unknown, too, as well as the question at what point of the route the Comacchio ship took over its lead freight. In terms of its construction, the Comacchio ship is a flat-bottomed freighter (length 21.0 m, width approx. 5.60 m) primarily for inland, coastal, and lagoon voyages (e.g., Berti 1990).

The destination of the lead cargo

The destination of the (lead) cargo can only be defined vaguely. A use for Rome itself is to be ruled out, because in this case, the shipping route from the Ionian Sea through the Strait of Messina into the Tyrrhenian Sea would be much cheaper and more convenient. According to current knowledge, various scenarios for the destination are conceivable, but they remain

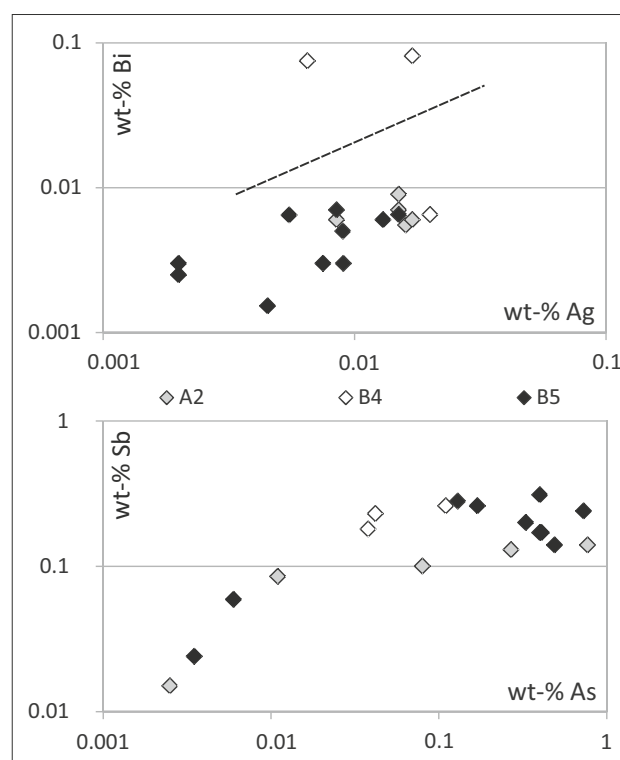


Fig. 7 XY-diagrams with Ag, As, Bi, and Sb contents in Comacchio lead ingots of type A2 (grey diamonds), B4 (white diamonds), and B5 (black diamonds) (M. Bode)

hypothetical. Because of the flat-bottomed type of the ship and the proximity of the archaeological site to the mouth of the river Po, it is tempting to assume that the final destination is upstream at the Po or near it (see Lavizzarri Pedrazzini 2010). A further journey to the ports along the north Adriatic coast (especially Aquileia) or instead a journey from these places were also considered (e.g., Rodá 2007; Domergue et al. 2012). A connection with the expansion of the Roman fleet base near Ravenna under Octavian/Augustus in the years 35–12 BC is also conceivable, whereby Agrippa's role remains unclear (compare, e.g., also Domergue et al. 2012). The linear distance between the location of the wreck and the military port is about 40 km.

Furthermore, the role of Agrippa as *patronus* of various cities in Italy and in the provinces must be pointed out. The ancient city of Claterna (now Maggio d'Ozzano dell'Emilia, pr. Bologna), whose patron according to an inscription was Agrippa, is relatively close (approx. 60 km linear distance) to the place where the Comacchio shipwreck was found (see Roddaz 1984, 2009).

Another scenario to be taken into account is the Alpine campaign of Drusus maior and Tiberius in 15 BC. In this context, northern Italy is seen as a deployment base and supply area for the Roman troops (Zanier 2010; Nuber 2010).

But although numerous lead slingshot projectiles from Roman troops came to light at the Roman military camp on the Septimer Pass and at the battlefield in the Crap Ses Gorge in Graubünden (Swiss), they do not match the lead isotope compositions of the ingots from Comacchio. In addition, there are also no other indications among the finds from the wreck that the cargo had a military character.

Conclusions

The lead isotopic evaluation of 20 lead ingots from the shipwreck of Comacchio made a reinterpretation of the previously published provenance of the lead metal necessary. The large lead-silver districts around Carthago Nova with the two areas around La Unión and Mazarrón (pr. Murcia) and the province of Almería are clearly ruled out as suppliers of the lead cargo according to lead isotope analysis. Although Agrippa's role as patron and therefore a person of influence of Carthago Nova is undisputed and his participation in the lead exploitation on the Iberian Peninsula can be proven also via an ingot find from Menorca (Rodà 2007; Nicolàs and Rodà, 2007), the lead load from Comacchio in the same way highlights his economic influence in the lead (and silver) production in ancient Macedonia in Augustan time. For the first time, a delivery of lead could be seen to emerge from an eastern Mediterranean region to Italy.

Certainly, this provenance result is not intended to suggest that the Adriatic coastal cities were mainly supplied with lead from the Aegean Sea. Spanish lead ingot loads might also have been shipped around the southern coast of the Italian mainland and across the Adriatic Sea, as individual finds of Iberian-type ingots with Spanish lead ore isotope signatures on the east coast of the Apennine peninsula, in Austria, and Croatia prove (e.g. Domergue et al. 1974; Ramallo Asensio and Berrocal Capparos 1994; Vitri et al. 1994; Picottini et al. 2003; Domergue and Piccottini 2004; Böhm and Weber 2005; Zaccaria 2008). This can also be seen in the transport of food (olive oil, fish sauces, etc.) from the Hispanic provinces of the Iberian Peninsula (Jurišić 2000, 2006).

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Data availability Not applicable.

Code availability Word 2016, Excel 2016, Corel Draw 12.

Declarations

Conflict of interest The authors declare no competing interests.

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